DynaRail

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DynaRail is a specialized rail vehicle dynamics tool developed at CAM (Center for Automated Mechanics). This development is in FORTRAN 95 using quad precision variables. This tool is based on the online solving approach. This approach does not need the commonly used wheel/rail contact geometry lookup tables. However, the kinematic module in DynaRail is readily able to generate the typical wheel/rail contact geometry table that is used by other codes. The track in DynaRail is constructed by analytical and/or measured segments similar to the methodology explained in [3]. The mathematical representations for track description are three-dimensional space curves including grades and vertical curves in vertical plane, which can be augmented to the tangents, transitional and constant curves in the horizontal plane.

In DynaRail, like most other programs of this class, the wheels and the rails are assumed to have realistic profiled surfaces and all possible contacts between them are assumed non-conformal or Hertzian. The contacts in DynaRail are modeled as rigid or elastic. The application of the rigid contact in DynaRail has been provided in [1]. This reference demonstrates many detailed results pertaining to the simulations of free and suspended wheelsets, as well as, a full vehicle system traveling on various types of standard analytical and real measured tracks.

REFERENCE FRAMES

Reference [1] gives a detailed description of most reference frames in DynaRail. The reference frames are track and contact based and well familiar to and commonly utilized by the practicing railroad engineers. The existence of the global frame {i} in DynaRail separates this tool from the other commercially available specialized programs of this class. All track frames are defined with respect to {i} as a function of the scalar arc length *s*, which represents the traveled distance. This frame is needed in order to accurately account for all the gravitational vectors due to twisting (roll), turning (yaw), rising and falling (pitch) of the track frame as a function of *s*. The relative turning of track with respect to this frame may be large rotation for long traveled distance on curves and therefore small angle assumption has not been utilized in any of the transformation matrices in DynaRail.

GENERALIZED COORDINATES AND FORCES

The coordinates representing the system configuration are defined by the relative translations and relative orientations of the body frame with respect to the track frame. The x, y, z, roll, pitch, and yaw are the physically meaningful generalized coordinates and the associated forces and moments are the physically meaningful generalized forces in DynaRail [1].These choices make the code intentionally the specialized tool and separate it from a general and one size fits all philosophy. Otherwise, the same ancient laws of physics are applied in terms of parameters which fit the wheel/rail application best.

CONTACT SEARCH MODELS

The rigid contacts in DynaRail fulfill the following definition online [1].

Definition 1: rigid contact: *A point on the profiled surface of the wheel and a point on the profiled surface of the rail have a <u>common position</u> in space which belongs to a plane that is the <u>common tangent plane</u> of the wheel and the rail at this point.*

The rigid contact model is not suitable for the simulation of the LD-benchmarking problems. In fact this benchmarking has been the main drive for adding the elastic contact model to DynaRail's library of elements.

For rigid contacts, it is enough to impose the algebraic constraints equivalent to Definition 1 at position, velocity and acceleration levels [2]. At position level, it means the two bodies contact each other without any penetration or separation along the common normal. This method with various levels and types of approximation has been implemented (in the form of online and offline techniques) in order to find the contact locations for both elastic and rigid wheel/rail contact models. This method, based on Definition 1, translates as the <u>rigid search</u> for contacts. The online or offline rigid search works as a function of the independent lateral rigid body displacement of the wheel relative to the rail. In elastic contacts, because of the elastic indentation, the lateral wheelset displacement is a sum of rigid body translation and elastic deformation. The scenarios which result in an excessive penetration at contact point (high contact angles like flange), the rigid search introduces inaccuracies in the contact determination. This inaccuracy was first pointed out by Pascal in the course of simulating the LD_benchmark problems. He proposed a quick and robust fix in which the elastic part of the lateral displacement (from previous time step) is subtracted from the gross lateral displacement before each search without altering the system generalized coordinates. It is worth noting that this fix is the best (possibly the only) remedy for the users of the lookup tables. This fix has been validated in DynaRail's online rigid search and the results have been presented to VOLPE, ENSCO, and FRA during a telephone conference early January 2006. This validation process intrigued a new and rigorous elastic search methodology. This methodology is not suitable for the users of the lookup tables since the contact deformation and the wheel elastic motions are not known offline. This methodology has been presented to the same group at the same time by CAM. This elastic search simultaneously finds the indentation and the contact location between the un-deformed and interfered surfaces of the wheel and the rail as required by the elastic contact model.

Definition 2: elastic contact: *A point on the profiled surface of the wheel and a point on the profiled surface of the rail along a <u>common normal</u> vector are in elastic contact if and only if the normal vector represents the only vector of local <u>maximum indentation</u> between the two interfered surfaces, Figure 1.*

This method is introduced by a set of algebraic relations that simply ensure fulfilling Definition 2 between two profiled surfaces at any given relative yaw rotation.

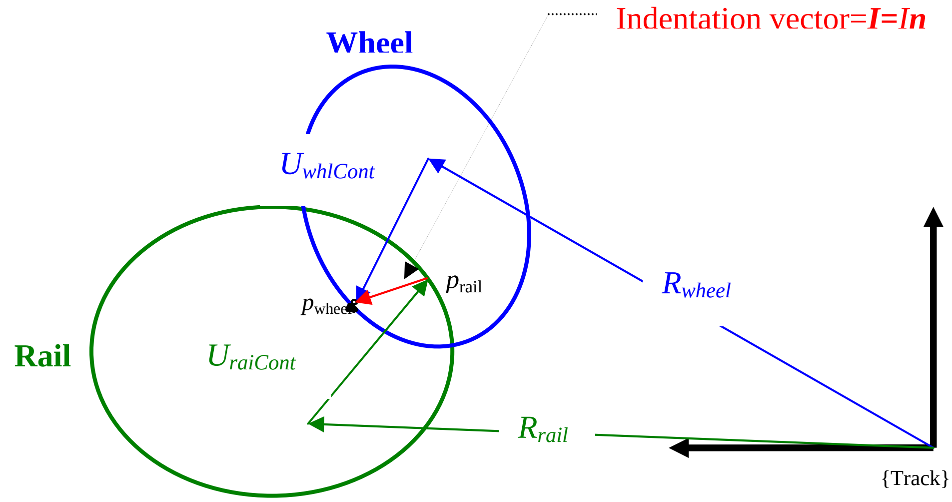

Figure 1. Profile interference representing elastic contact at any relative yaw rotation

Considering Figure 1, one can arrive at the following constraint equations (1) and (2) to guarantee the proposed solution. Equation (1) is a loop vector equation and equation (2) is the in plane alignment equation which together fulfill Definition 2.

$$\vec{R}_{rail} + \vec{U}_{railContact} + I\vec{n}_{rail} = \vec{R}_{wheel} + \vec{U}_{wheelContact} \quad (1)$$

$$\vec{t}_{wheel} \bullet \vec{n}_{rail} = 0 \quad (2)$$

Clearly, the loop equation together with the alignment condition guarantee the indentation vector originating from the rail at point p_{rail} must be along (not just parallel) to the wheel normal at point $p_{wheel,}$. If this does not happen, the loop does not close (violation of equation 1). These relations also signify that the magnitude of the indentation vector is always a local (relative) extrema since it is along the common normal (minimum separation or maximum indentation).

Since all vectors are in track frame, the rotation matrices in the above equations are skipped for clarity. At each time step, all the rotation matrices are known and treated as constants in solving these algebraic relations. Where;

$\vec{R}_{rail}$ =The position of a point rigidly attached to the rail.

$\vec{R}_{wheel}$ =The position of a point rigidly attached to the wheel.

$\vec{U}_{railContact}$ =The position vector of the contact point which is a function of the contact position, $S_{rail.}$

$\vec{U}_{wheelContact}$ =The position vector of the contact point which is a function of the contact position, S_{wheel}.

$\vec{n}_{rail}$ =The unit normal vector at rail point of contact, which is a function of contact location S_{rail}.

$\vec{t}_{wheel}$ =The in-plane unit tangent vector at wheel point of contact, which is a function of contact location $S_{wheel.}$

I = The magnitude of maximum indentation or minimum separation.

The vector equations 1 and 2 are three algebraic equations in three unknowns; $S_{wheel,}$ $S_{rail,}$ and I, which can be solved using Newton-Raphson iterations. These algebraic relations can be applied between the contacting surfaces at each time step for as many times as possible (depending on the number of predetermined singularities in the profiles). The solution can be achieved for cases with penetration, osculation or even separation. This is the reason that achieving online solution for elastic contact is far easier than rigid contact for the later requires zero indentation or osculation only.

Once the contact location and the indentation are determined, the elastic contact is imposed by solving the Hertzian problem online for the resulting elastic force and contact size. This approach is currently implemented in DynaRail, which has been used to produce the results for the LD_benchmark problems.

Comparison to the recent work by Pombo and Ambrosio

The problem in Figure 1 is described in 2-D since it shows the profiles at a given yaw rotation. In its 3-D equivalence, one can simply regard equation (1) as a 3-D vector and add another alignment equation like equation (2) in out of plane direction [2]. After converting to 3-D representation, by dot producting once the in plane and next the out of plane tangent vectors by equation (1) then the resulting two scalar equations together with the two alignment equations are exactly the same four scalar equations of equation (7) in Reference 3. These dot products eliminate the indentation vector from equation (1). Doing so, the ability to solve, for the contact locations and the indentation simultaneously, will be lost. Other than this loss, the elastic search method as proposed here is equivalent to the approach presented in Reference 3 or equivalently implemented in Samsrail as marker 44.

Concluding Remarks

Most codes with elastic contact model rightfully use the Hertz contact theory. The elastic wheel/rail contact model using this theory was first practiced by Kik and Pascal many years ago.

The major differences among codes with elastic contacts still remain in the accuracy at which the contact locations and the elastic deformations (or indentations) are determined. By applying the Hertz theory (which is merely borrowing a historic solution), the elastic contact can be successfully implemented in few lines of coding.

On the other hand, due to various kinematic and dynamic simplifications, the major differences among codes with rigid contact are much more complex than codes with Hertzian elastic contact. But, regardless of rigid or elastic contact, the common and most important issues still remain as the locations, the shapes and the sizes of contacts and the accuracy at which these are determined.

References

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